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AN OVERVIEW OF TECHNOLOGY FOR JAMMING EARLY WARNING AIRCRAFT IN THE NATIONAL AIR DEFENSE SYSTEM (PART 1)

by

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AN OVERVIEW OF TECHNOLOGY FOR JAMMING EARLY WARNING AIRCRAFT IN THE NATIONAL AIR DEFENSE SYSTEM (PART 1)

(Romanized title: "*Guotu Fangkong Xitongzhong Ganrao Yujingji Zongti Jishu (1)*"

by Liang Baichuan (Xi'an University of Electronic Science and Technology)

Abstract: Based on his research of the characteristics of different electronic systems of early warning aircraft, the author proposes methods of countering early warning aircraft, and studies techniques of jamming their radar, communications systems, and Identification Friend or Foe [IFF] systems.

Key words: electronic countermeasures, air defense system, electronic jamming equipment, jammer, communications system

1. Different kinds of early warning aircraft systems, their functions and composition

Early warning airplanes and high atmospheric tethered balloons are called Airborne Early Warning (AEW) for short. AEW organically combines surveillance radar, computers, and other electronic equipment, and unites early warning, command, communications, control, and intelligence functions. In strategic terms, it can detect, identify, and track invading strategic bombers and cruise missiles, and detect targets for ground-based air defense weapons and interceptors and guide them to their targets; in tactical terms, it can keep watch over and reconnoiter the deployment and maneuvers of enemy forces, and promptly determine the possibility of surprise attacks by the enemy. It can also provide strong support for friendly forces when they launch offensives.

1.1 The functions of AEW aircraft

The roles of AEW can be summed up as follows:

a. Combat control AEW can provide information about the positions of targets of interest as well as guidance information to combat aircraft, and guide fighter aircraft to positions where they can intercept and fire on their targets. AEW sends information concerning flight direction, altitude, velocity, and interception methods to fighter aircraft through radio voice contact, digital, or data communications methods. After this, every ten seconds, it sends information on direction and distance from the target, so that the fighters can change their direction, velocity, and altitude, until they can use their own sensors to intercept the targets. Afterwards, AEW maintains surveillance of the interception process, so that it can continue to provide target information to the fighter planes.

b. Attack guidance AEW can guide bombers to bomb targets at designated areas. If the targets are fixed, AEW can provide their coordinates. If the targets are mobile, other combat aircraft are needed to aid in positioning and identifying them. In addition, AEW can also organize groups of attack aircraft, keep lookout over their flight paths, or change the target they are attacking. When friendly attack aircraft are intercepted, AEW can guide the fighter aircraft in their formation to protect the attack aircraft. To prevent the formation from being attacked by surface-to-air missiles or fire-control radar, the electronic support measures (ESM) in AEW [aircraft] work in coordination with the ESM in the aircraft in the formation to carry out tactical evasion. When the formation returns, it is necessary to identify the returning airplanes, in order to prevent enemy planes from mixing in with them. In addition, AEW is also responsible for in-flight refueling of returning aircraft, so that attack aircraft can continuously enter combat.

c. Air-sea searching AEW [aircraft], together with other search planes, can search for targets on the surface of the water. AEW aircraft use their radar ESM and IFF systems to quickly determine the positions of enemy ships and choose targets for attack.

Other functions of AEW include rescue of downed airmen, organization of aircraft formations, in-flight refueling, et cetera.

1.2 Characteristics of AEW aircraft

AEW platforms are equipped with surveillance radar, data processing, data display and control, IFF, communications, navigation, passive detection, and other electronic systems. The properties of AEW systems in all countries are virtually the same. Typical AEW aircraft include the United States' E-3A Sentry and the former Soviet Union's Il-76. Early warning aircraft have the following characteristics:

a. Large radar surveillance area AEW aircraft can search out and track distant airborne targets, and can detect ships and targets on the ground and at low altitudes. From an altitude of 9000 meters, airborne surveillance radar can detect high-altitude targets 500-650 kilometers away, low-altitude targets 300-400 kilometers away, and cruise missiles 270 kilometers away. They can also detect near targets that suddenly appear below the AEW radar, such as ships.

b. Long early warning time The early warning radar on the E-3A can detect targets up to 1200 kilometers away and provide 30 minutes of early warning time, which is five times as much time as most ground-based warning radar can provide.

c. Strong counter-jamming capabilities The E-3A has strong optical and electronic countermeasures capabilities, and can counter clutter jamming, passive jamming, and electronic jamming.

d. Strong computer data-processing capabilities The E-3A employs a 4 Pi CC-1 (or 4 Pi CC-2) computer, which has a large storage capacity and rapid calculation speed. It can simultaneously track 600 targets, identify 200 targets, and process from 300 to 400 targets.

e. Strong survivability If [the E-3A] discovers attacking aircraft at a long distance, it can immediately guide interceptors to their targets. Because it is equipped with chaff[1] dispensers and self-defense jamming and infrared devices, the E-3A can discharge jamming signals and carry out evasive flight measures when enemy aircraft come near, in addition to directing ground-

[1] I have translated "*botiao*," which literally means "foil strips," as "chaff." No translation was found for *botiao* in any dictionary.

based antiaircraft fire.

f. Multiple functions and simultaneous tracking of multiple targets AEW can not only guide airplanes to carry out air defense, air superiority, air blockade, close air support, rescue, reconnaissance, convoy escort, and other missions, it can also position and track targets for [friendly] jamming aircraft [i.e., wild weasels] and guide tens or even hundreds of interceptors into combat. In addition, it can provide battle zone commanders with many kinds of intelligence, in order to unite command of land, sea, and air forces.

g. Command efficiency Employing AEW can raise the efficiency of air defense systems by 15 to 30 times, increase the amount of interceptions of and attacks on enemy planes by 35 to 150%, and reduce attacks on the rear by enemy planes by 15 to 55%.

1.3 Composition of early warning aircraft systems

The main systems of AEW, besides the platform aircraft themselves, are the following:

1.3.1 Surveillance radar systems

Usually, surveillance radar is a kind of multiple-function, three-coordinate radar which employs Pulse Doppler [PD] and pulse compression systems, and possesses PD Non-Elevation Scan (PDNES), PD Elevation Scan (PDES), Beyond-The-Horizon (BTH), pure pulse operation, passive, maritime, alternating, and other modes.

1.3.2 Data processing systems

Data processing systems are the heart of AEW. Their processing speed can be as high as one million calculations per second.

1.3.3 Data display and control systems

Data display and control systems are combined manually-operated and human-machine interface systems. They can convert computer code into television signals and change manually-input data into numerical form. They have multiple-use control displays and teleprinters.

1.3.4 Identification Friend or Foe systems

IFF is used in concert with surveillance radar. As it obtains target information, it simultaneously identifies friendly and enemy aircraft. Normally, with each scan, it can interrogate 200 different targets, compare and contrast the targets' response coding signals with data saved in the on-board computer, acquire the targets' distance, position, and elevation data, and distinguish friendly from enemy targets. If it discovers an enemy target, it can immediately send out a warning to friendly ground-based control centers and their weapons.

1.3.5 Communications systems

AEW communications systems include internal and external communications. External communications systems are primarily used as links among AEW aircraft and between AEW aircraft, the airplanes they lead, and ground-based fighting units. Generally, AEW aircraft have between ten and twenty lines of communications,

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including VHF, UHF FM, UHF AM, HF, and other transceivers, as well as VHF, UHF, and other warning receivers and goniometers. In addition, there are satellite communications terminals, time division multichannel access communications terminals, et cetera.

1.3.6 Navigation systems

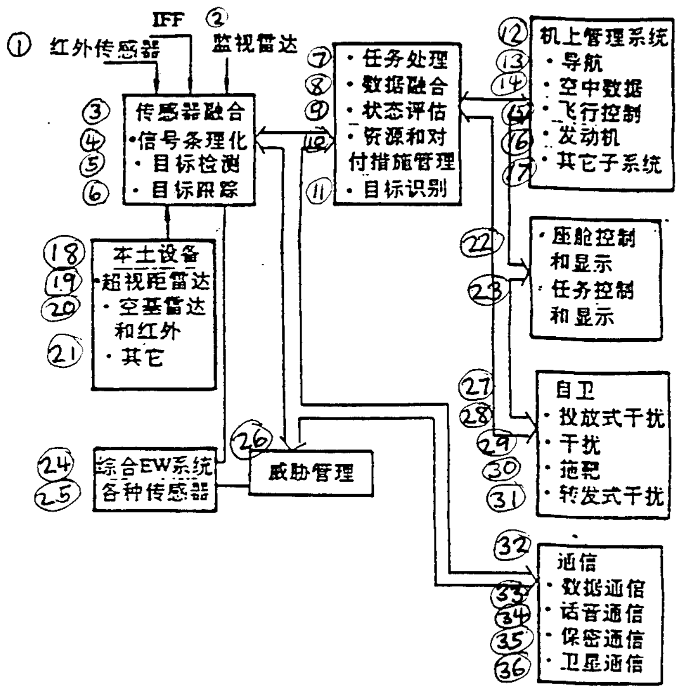
Navigation systems provide AEW with flight path, speed, and position data. Kinds of navigation systems include inertial navigation, Doppler navigation, et cetera.

1.3.7 Passive detection systems

Passive detection systems raise the target detection, classification, and identification abilities of AEW through analysis and comparison of signals radiated from targets. The primary passive detection systems include ESM and infrared detectors.

Figure 1 shows a box diagram of the composition of AEW.

Figure 1 AEW System Box Diagram



Key: (1). Infrared sensors. (2). Surveillance radar. (3). Fusion of sensors. (4). Signal organization. (5). Target detection. (6). Target tracking. (7). Mission processing. (8). Data fusion. (9). Estimate of the situation. (10). Management of resources and countermeasures. (11). Target identification. (12). Airborne management systems. (13). Navigation. (14). Air data. (15). Flight control. (16). Engines. (17). Other electronic systems. (18). Home territory installations. (19). Beyond-the-horizon radar. (20). Airborne radar and infrared systems. (21). Others. (22). Cockpit control and display. (23). Mission control and display. (24). Combined EW systems. (25). Sensors. (26). Threat management. (27). Self defense. (28). Chaff jamming. (29). Jamming. (30). Target towing. (31). Transmission jamming. (32). Communications. (33). Data communications. (34). Voice communications. (35). Secret communications. (36). Satellite communications.

2. Airborne early warning radar and other electronic equipment in early warning aircraft systems

Below, as a study of possible AEW countermeasures, an analysis of primary airborne sensors is made.

2.1 Early warning radar

Today, there are more than 20 firms producing about 100 kinds of early warning radar. Half of the early warning radars are modified or renamed versions of certain other radars.

There are three different kinds of early warning radar, each with different uses: airborne early warning, battlefield surveillance, and ocean search radar. Their tactical and technological properties also differ according to their missions. Here, the functions of several kinds of representative surveillance radar are presented.

2.1.1 The E-2C's airborne surveillance radar

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The E-2C Hawkeye flew for the first time on January 20, 1971 with a flight crew of five, three of whom were electronic equipment operators. The E-2C can fly continuously without refueling for six to seven hours, and has a speed of 410 km/h and a cruising altitude of 6.1 to 9.1 km. In addition to the United States, Japan, Singapore, Egypt, and Israel all use this AEW aircraft.

Airborne surveillance radar is already in its fourth generation of development. The one presently installed [on the E-2C] is the AN/APS-139, delivered in 1987, which is an improved version of the third-generation AN/APS-138 airborne surveillance radar. It is estimated that the fifth-generation AN/APS-145 airborne surveillance radar was installed in 1990.

The main parameters of the AN/APS-138 are listed in Table 1.

Table 1 Two kinds of AEW surveillance radar

(1) 预警机	E-2C	E-3A
(2) 监视雷达	AN/APS-138	AN/APY-2
(3) 频率	425MHz	(4) S波段
(5) 功率	(6) 峰值:1MW;平值:3.8kW	(7) 兆瓦级
(8) 工作比	3.8/1000	
(9) 天线增益	21.5dB	
(10) 波束宽度	(11) 方位6.6°,机扫360°,仰角20°,不扫	(12) 方位0.73°,机械扫描360°,仰角3.5°,±15°机扫,±30°电扫
(13) 旁瓣电平	−26dB	−50dB
(14) 数据率	6r/s	6r/s
(15) 重频	300Hz	(16) 低(超视距工作时);高(三脉冲参差)
(17) 波形	(18) 固定(线性FM) 压缩比=13μs/220ns=59	(19) 有7种工作方式:(1)无仰扫PD;(2)仰扫PD,仰角可电扫测量;(3)超视距,检测杂波区外目标,用低重频,线性调频;(4)海用方式,用窄脉冲减少海杂波尺寸;(5)无源方式,用两架E-3A对干扰源测向定位;(6)试验/维修方式;(7)预热方式
(20) 抗干扰	(21) ·有10个信道频率,人工控制扫描-扫描式跳频,频率可变范围40MHz (22) ·AMTI(三脉冲对消) (23) ·16点FFT滤波 ·SLC (24) ·没有干扰检测和跟踪能力	
(25) 检测距离	(26) ·对水面上A-6飞机370km (27) ·对地面上A-6飞机148~260km	

Key: (1). Early warning aircraft. (2). Surveillance radar. (3). Frequency. (4). *S* wave band. (5). Power. (6). Peak: 1MW; Average: 3.8KW. (7). Megawatt level. (8). Operation ratio. (9). Antenna gain. (10). Beam width. (11). Azimuth 6.6°, mechanical scanning 360°, elevation angle 20°, non-scanning. (12). Azimuth 0.73°, mechanical scanning 360°, elevation angle 3.5°, ±15° mechanical scanning, ±30° electronic scanning. (13). Sidelobe level. (14). Data rate. (15). Repetition frequency. (16). Low (during beyond-the-horizon operation); High (three-pulse diversity). (17). Wave form. (18). Fixed (linear FM); compression ratio = 13 μs / 220 ns = 59. (19). Has seven different modes of operation: (1) Non-elevation scanning PD; (2) Elevation scanning PD. Elevation angle can be measured with electronic scanning; (3) Beyond-the-horizon, detection of targets outside the clutter zone. Uses low repetition frequencies and linear frequency

modulation; (4) Maritime mode. Uses narrow pulses to reduce the size of sea noise waves; (5) Passive mode. Two E-3As are used to determine the direction and position of jamming sources; (6) Testing/maintenance mode; (7) Standby mode. (20). Antijamming. (21). Has ten channel frequencies, manually controlled scanning–scanning frequency agility, and a frequency adjustment range of 40MHz. (22). AMTI [Airborne Moving Target Indicator] (three-pulse cancellation). (23). 16 point FFI filter. (24). Non-jamming detection and tracking abilities. (25). Detection distance. (26). Of an A-6 aircraft on the water's surface: 370 km. (27). Of an A-6 aircraft on the ground: 148 to 250 km.

2.1.2 E-3A airborne surveillance radar

The E-3A platform is a modified Boeing 707-320B. It has a continuous flying time of 8 hours, a speed of 666 km/h, and an altitude of 8800 to 9400 meters. It has 13 electronics operators and a flight crew of four. Besides the United States, NATO and Saudi Arabia are also equipped with this aircraft.

The main technical parameters of the AN/APY-2 airborne surveillance radar appear in Table 1.

In brief, the characteristics of present-day airborne surveillance radar are as follows:

a. Its primary operating frequencies are the L and S bands, and it operates infrequently on the X band. Band choice is related to detection distance and size of the target being detected, as well as the precision of target detection. Low wave bands can produce high-power signals and detect targets with small radar reflection areas and stealth targets, but their target measurement accuracy is low. Because the jamming environment in the UHF band is very complex, low wave bands primarily use the L band.

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The high frequency end is used to raise angle resolution power, and wide bandwidth aids antijamming.

b. The radar operation system primarily uses AMTI and PD, and takes into consideration multiple function detection demands, such as using pulse compression signals during beyond-the-

horizon detection. AMTI and PD have clutter-countering capabilities, but improvements to PD can make it greater than AMTI by 20 to 30 dB.

c. The radar employs low sidelobe antennas and sidelobe cancellation (SLC) technology. The transmitting antenna's low sidelobe is used against surveillance, and the receiving antenna's sidelobe is used for antijamming. The gain rate of single-pass major and minor lobes can reach 50 dB. SLC is widely used in early warning radars. It forms valley points in the directional diagram from the direction of the jamming source, and thus lowers the effectiveness of support jamming. By using digital sidelobe cancellation, it is possible to form valley points simultaneously in several directions.

d. Frequency agility and PD systems are not compatible. Most radars employ wave-wave frequency-hopping technology.

2.2 IFF systems

The functions of the IFF systems of AEW are: (1) distinguishing between military and civilian airplanes; (2) monitoring combat between two airplanes. When crews of attack planes cannot see enemy planes, IFF provides flight coordinates to the attacking planes; (3) preventing multiple tracking of a single target; (4) as attack planes return from a mission, it distinguishes between friendly and enemy planes according to their military response codes, to prevent opposing planes from mixing in with friendly planes.

The IFF systems of the E-2C and E-3A are the MKX and MKX-II devices. They both operate on the L band, their interrogation pulse carrier frequency is 1030 MHz, their response frequency is 1090 MHz, and their signal form is pulse-position modulation. To work in coordination with NATO's identification friend or foe systems, the United States is developing the MK-XV device. The MK-XV uses spread-spectrum response wave forms.

The main parameters of the MK series of IFF devices appear in Table 2.

Table 2 Typical parameters of MK model IFF devices

(1) 参 数	(2) 询 问 机	(3) 应 答 机
(4) 频 率	1030±0.3MHz	1090±3MHz
(5) 极 化	(6) 垂直	(6) 垂直
(7) 询问方式	(8) 由 P1.P2.P3 三脉冲组成。	(9) 应答信号.由 P1.P2 间成帧脉冲组成
	(10) 询问方式决定于 P1 和 P3 的间隔	(11) P1 与 P2 间隔为 20.3±0.1μs，(13) 帧内 P1～P2
	(12) 方式 1(军用)3±0.1μs	间有 13 个脉冲.脉冲间间隔均为 1.45μs
	(14) 方式 2(军用)5±0.2μs	
	(15) 方式 3/A(普通)5±0.2μs	
	(16) 方式 B(民用)17±0.2μs	
	(17) 方式 C(普通高度)21±0.2μs	
	(18) 方式 D(民用、备分)25±0.2μs	
(19) 旁瓣抑制	(20) 脉冲 P2 限在 P1 后.间隔 2±0.18μs	
(21) 脉冲宽度	0.8±0.18μs	0.45±0.1μs
(22) 脉组宽度	300-400Hz	
(23) 输出功率	(24) 1～1.5kW(峰值)	(24) 500W(峰值)
(25) 天线转速	6～15r/s	
	(26) (phalcon 为固态相控阵)	
(27) 波速宽度	2.8～7.0	

Key: (1). Parameter. (2). Interrogation device. (3). Response device. (4). Frequency. (5). Polarization. (6). Vertical. (7). Interrogation method. (8). Composed of P1, P2, and P3 pulses. (9). Response signal is formed of frame pulse between P1 and P2. (10). Interrogation method is determined by interval between P1 and P3. (11). Interval between P1 and P2 is 20.3±0.1 μs. (12). Mode 1 (military) 3.0±1 μs. (13). 13 pulses are in the frame between P1 and P2. Interpulse intervals are all 1.45 μs. (14). Mode 2 (military) 5±0.2 μs. (15). Mode 3/A (common) 5±0.2 μs. (16). Mode B (civilian) 17±0.2 μs. (17). Mode C (common altitude) 21±0.2 μs. (18). Mode D (civilian, backup) 25±0.2 μs. (19). Sidelobe suppression. (20). Pulse P2 follows behind pulse P1. Interval is 2±0.18 μs. (21). Pulse width. (22). Pulse group width. (23). Output power. (24). … (Peak value). (25). Antenna rotating speed. (26). (Phalcon is solid-state phased array). (27). Wave velocity width.

2.3 Navigation systems

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All present-day AEW aircraft have inertial navigation and Doppler navigation systems. The E-2C has the AN/ASN-92 inertial navigation system and AN/APN-153 Doppler navigation radar. The E-3A uses the AN/ASN-119 inertial navigation system. The direction of development of the AN/ARN-120 Omega navigation system and the AN/APN-213 Doppler navigation system is to enhance the GPS navigation system.

Doppler navigation systems are used for altimetry. They have low power (several watts or several dozens of watts), a low beam incidence angle, operate on the Ka band (13.3 GHz), and are generally difficult to jam. GPS is an outer space-based navigation system. Its outer space portion is composed of a group of 18 or more satellites, and it provides world-wide coverage. The satellites transmit double code false noise signals. One of these codes is used in signal interception and rough navigation, and the other is used in precise navigation. Transmitted signal frequencies are, respectively, 1575.42 MHz and 1227.6 MHz. By receiving signals from at least 4 satellites, GPS receivers derive the user's space coordinates and time. GPS receivers contain duplicates of each satellite's false random codes, and correlate these with the signals they receive to measure the distance between each satellite. GPS is highly susceptible to jamming. If GPS is subject to 10W power jamming transmitted from a high-atmospheric jamming source, its receivers will be unable to operate. The Omega navigation system is susceptible to jamming from two high-power jammers.

2.4 Communications systems

AEW aircraft have many methods of communications, as well as wide frequency bands.

2.4.1 Data links

Data links are used for course control of fighter aircraft and combat command. There are three kinds of data links.

a. Tactical data information link A (TADIL-A). This is a secret duplex communications [method] with an operating frequency of 2–30 MHz, which can also use frequencies between 225

and 400 MHz. It uses a modem to change data signals for controlling combat aircraft into phase-modulated speech sounds, and the receiving terminal changes audio frequency signals into data signals.

b. Tactical data information link C (TADIL-C). This is a non-secret simplex/duplex communications [method] which uses the UHF frequency and has an FSK [Frequency Shift Keying] operating mode. It is used to provide combat aircraft with guidance and control information through time division modes after aircraft and target routes have been calculated. It is another important target of electronic countermeasures.

c. Joint tactical information distribution system (JTIDS). This is the most advanced secret information system. It has already been installed on the E-3A and will soon be installed on the E-2C. This system's operating frequency is 960–1215 MHz. It is a random code spreading frequency-hopping system, with a communications distance of 300–500 nautical miles.

2.4.2 Voice communications

Voice communications are used in many communications interfaces. AEW [aircraft] have duplex voice and voice-data relay operating capabilities for carrying out air-to-air or air-to-ground communications. The voice simplex communications systems of the E-2C and E-3A include:

HF communications — the AN/ARQ-24, used for voice and data communications.

UHF communications — the AN/ARC-158, used for voice-data and data-voice relays.

VHF communications — the AN/ARC-51A, used only for voice communications with the surface.

In addition, AEW aircraft can work in coordination with satellite communications, but it cannot yet be confirmed that present AEW systems have equipment for communicating with satellites.

2.5 ESM and photoelectric systems

ESM [Electronic Support Measures] are used to aid radar and IFF recognition of specific

targets (such as shipboard air search radar and surface-to-air missile bases' fire-control radar), as well as to aid positioning.

The E-2C's ESM system is the AN/ALR-73. This is a combined heterodyne reconnaissance receiver and jamming apparatus direction-finding system.

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Its frequency range is from 0.5–18 GHz, its root-mean-square direction-finding precision is 3.5°, and it can only analyze simple wave forms.

Photoelectric detection systems can supplement AEW microwave radar, but atmospheric attenuation severely limits the effective distance of photoelectric systems. In addition, surface (or sea) thermal radiation background interference also affects the operation of photoelectric systems. Therefore, the photoelectric systems on AEW aircraft are used only for infrared warning and to prevent attacks from air-to-air and surface-to-air infrared guided missiles. A self-defense method against infrared guided missiles is infrared tracer bullets.

3. Counter-Electronic Support Measures capabilities of early warning radars

Counter-electronic support measures (CESM) can delay or prevent the interception and identification of signals by ESM interception receivers. There are two kinds of CESM: LPIn, or Lower Probability of Interception, and LPId, or Lower Probability of Identification. Some call this Lower Probability of Identification/Interception technology (LPI/I).

To successfully jam AEW, it is necessary to fulfill these two conditions: first, the jamming must be effective, and must begin before the target is within destruction distance; second, the effectiveness of jamming is related to radar's time of use. In the hands of experienced operators, CESM technology can reduce the effectiveness of jamming to zero. But because ECM and ESM signal identification methods are always changing, the effectiveness of CESM will be reduced as well. Thus, radar signal characteristics of AEW radar will also change periodically.

Below is a brief explanation of the CESM technology of AEW aircraft. Of course, some CESM are not used on small AEW platforms.

3.1 Transmitter CESM

If any one of the characteristics of radar (including PRF, PW, RF, polarization, scanning modulation, etc.) changes, it will cause identification to be confused and may cause choice of jamming methods to be delayed. These changes can cause one radar to seem to be another one, in order to deceive ESM or anti-radiation missiles (ARM). Many special methods of transmission have been designed, such as simultaneously sending two pulses with different frequencies that are within the same frequency band. Breaking up pulses equally confuses ESM systems. Modern master amplifier radar transmitters can quickly change the characteristics of radar pulses or frequencies.

Selecting operating frequency bands is a counter-electronic support measures method. The higher the frequency, the more difficult a signal is to intercept. Frequency agility and spread spectrum make ESM more complex, and double frequency bands and dual modes (such as active-passive and infrared-radar) make ESM more diverse.

Infrared detection systems are used on large AEW aircraft, and can be used as supplements to microwave AEW.

Double-station operation is an effective CESM against AEW and ARMs. This method can let one AEW airplane employ its radar to carry out passive detection while an airborne or surface-based transmitter actively transmits against a target.

False noise modulation is an excellent LPI technique. Because the radar signal spectrum is broad, the complexity of ESM receivers is increased. Repetition frequency flutter and variability (pulse spacing variation) also make ESM receivers more complex, and, furthermore, increase the bandwidth coverage of jammers.

3.2 Antenna counter-electronic support measures

There are many antenna CESM techniques, such as using a Precursor beam antenna whose primary beam characteristics are CESM, and which uses a large antenna to reduce beam width.

4. Counter-jamming capabilities of early warning aircraft radar

The above-mentioned CESM can be special kinds of AEW radar counter-jamming techniques. Their use can cause the enemy

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to delay use of ECM operations or to adopt inappropriate ECM techniques. Therefore, when discussing AEW radar counter-jamming, some things may be repeated. The most common and complete AEW radar counter-jamming techniques are as follows: receiver anti-saturation; constant false alarm; enhancing the signal-to-jamming ratio; jamming discrimination; tracking maintenance; and control of inappropriate targets.

4.1 Transmitter counter-jamming

•*Frequency band selection* Using the highest frequencies makes AEW radar difficult to detect and jam.

•*Frequency agility* This is used to render enemy ESM useless, to complicate enemy signal interception and identification, to make enemy jammer power disperse, and to lower jamming power density. But since coherent accumulation and anti-surface clutter take a long time, it is impossible to use complete pulse spacing frequency agility. It is only possible to use predetermined frequency agility methods, such as switching between a fixed group of frequencies. The number of frequencies used should be as large as possible, the range of frequencies should be as broad as possible, and frequency hopping should be done at random. Doppler processing requires a specialized frequency agility method, such as sending multiple pulses when at a certain frequency, then randomly changing to new frequencies, or randomly sending at several predetermined frequencies and saving Doppler echoes in storage memory for later processing. AEW radar frequencies must jump at least $1/\tau$ to have a bearing on the target [original meaning unclear]. If there is no jamming on the frequency used at present, it is unnecessary to jump to another frequency. The number of pulses sent at given frequencies is different for each group.

•*Output power control* The required emission power for detecting a target with an RCS [radar cross section] of approximately 100 square meters at sea can be used to detect an airplane with an RCS much smaller than that. Lowering power can prevent detection by ESM.

•*Airborne early warning PRF [Pulse Repetition Frequency] agility* A combination of RF

and PRF agility can raise the effectiveness of ECCM. Even if one is using a fixed PRF, it should have some flutter. PRF flutter increases the effectiveness of frequency agility, and can be used to effectively counter false targets.

•*Wave-form design* False noise and other non-sine waves can be used both to counter electronic support measures and to disperse jamming power. Because diphase code noise modulation which uses a quadratic harmonic detection program can be detected easily, most AEW aircraft use multiphase false noise modulation. Although application of false noise radar may make AEW radar more complex, it is an effective method of countering anti-radiation missiles.

•*Pulse compression* Pulse compression can raise distance resolving power, and aids in distinguishing targets among chaff. If AEW radar does not employ pulse compression, it should use a pulse width that is as narrow as possible in an environment where there is chaff.

4.2 Antenna ECCM

The antenna is a key part of AEW antijamming. In conditions of chaff jamming, the horizontal and elevation angles of AEW radar should be as small as possible, in order to reduce the volume of chaff reflection.

•*Monopulse reception* Monopulse reception is an antijamming measure that uses beam sharpening methods.

•*Principal beam jamming cancellation techniques* Jamming within the principal beam will conceal a target. This takes place when aircraft not equipped with jammers fly along with aircraft equipped with self-defense jammers, and may also happen when airplanes not carrying jammers form a line with airborne long-distance support jamming. When the directional included angle of the target and the jammer is one-tenth of the beam width and angle measurement accuracy is one-twentieth of the beam width, most principal beam jamming cancellation techniques can be used.

•*Polarization agility* If several kinds of polarization are used while receiving, it is possible to discover one kind of polarization with a large signal-to-jamming ratio, even though most jammers use circular polarization.

•*Sidelobe cancellation (SLC)* SLC is primarily used to counter long-distance support jamming and false-target generators. It can counter both noise jamming and pulse jamming. Each jammer has at least one cancellation ring and an auxiliary antenna which are used to produce valley points in the direction of jamming. However, SLC can only be used in the AEW systems of large aircraft.

•*Sidelobe blanking (SLB)* SLB was originally used to counter the pulse jamming of nearby radar, as well as to decrease

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the amount of surface clutter entering the sidelobes of airborne search radar. With the appearance of deception jamming, SLB was also applied to countering active jamming. SLB is only used to counter low operating ratio (less than 0.01) jamming, not to counter noise jamming. But when jamming is located in the primary beam, [even though] the jamming cannot be controlled, it is still possible to determine the direction angle of the jamming, as this is beneficial for determining the position of the jammer through triangular positioning.

4.3 AEW radar receiver antijamming

No matter how the AEW radar transmitter frequency changes or what the method of frequency agility is, ESM receivers always attempt to monitor radar transmission frequencies.

The operating environment faced by AEW radar is different from that faced by maritime radar. AEW aircraft fly above friendly high-power radar and radio transmitters. These include FM broadcasts, whose high-power transmissions enter the front end of the radar, causing overloads and decreasing sensitivity. Therefore, it is necessary to install correcting wave filters at the front ends of radar receivers to prevent penetration by unneeded signals. Operating in an environment with a jam-to-signal ratio of 20 to 40 dB demands that AEW radar receivers cannot oscillate or be saturated.

•*MTI* This was originally used to counter severe surface clutter, but is now widely used against chaff jamming. The AEW chaff environment is different from that encountered by surface radar, in that chaff and airplane targets have different radial velocities relative to AEW motion. Ordinary pulse-cancellation MTI is inappropriate for use in AEW radar, but self-

adaptive MTI is an effective method. The responding notch in its receiver can automatically aim at the center of AEW surface clutter or the chaff's f_d.

•*Sideband techniques* These consist of a combination of the main channel and several sideband channels. When jamming in the sideband channels is discovered, the main channel should be temporarily blanked, and, for example, two sideband channels on both sides of the main channel frequency should be used.

•*Constant False Alarm Rate (CFAR)* CFAR [ranges] from simple manual gain control to many kinds of complex programs. CFAR may appear in the middle frequencies or video frequencies of AEW radar. CFAR can prevent the computer from overloading due to mistaking noise pulses for real targets, but cannot make the radar detect more targets. On the contrary, it makes it impossible to detect targets that give off weak signals. CFAR is affected by jamming spectrum characteristics. There are three kinds of CFAR circuits: LogCFAR, unit average CFAR, and distribution-unrelated CFAR (non-parameter CFAR). The best of these for dealing with the Weibull distribution clutter spectrum is non-parameter CFAR.

•*Dickefix* Throughout the jamming signal operational period of most radar receivers, the receiver will produce ringing, which will cause false alarms to increase. The size of suppression of false alarms by Dickefix is equal to the bandwidth ratio of wide to narrow bands. Rapid-scanning continuous-wave (CW) jamming is a way to counter Dickefix. To avoid capture of slice, the following method can be used: when receiving strong offset frequency CW signals, use a slice circuit and related logic units to blank the jamming added to the MTI output.

4.4 The role of ESM in AEW

Passive detection systems are highly concealable. They do not expose the airplane that carries them, they do not attract attacks by anti-radiation missiles, and they are not subject to electronic jamming. They have a wide range of applications. They can detect any target carrier, as long as it radiates electromagnetic waves, and are not affected by stealth technology. Passive detection systems have precise identification capabilities, and, by using electronic information, can tell the model of the radiation source and thus deduce what type of platform employs that radiation source. They can even determine the individual number on a certain platform. Thus, electronic support measures play an important role in advance early warning.

A foreign journal made a full comparison of sensors used on AEW platforms (see Table 3).

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Table 3 Comparison of Sensor Functions

① 传感器类型	RADAR	IFF	ESM/Elint	CSM/Comint	IR	$\sum$
② 定位能力	++	+	+/−	−	−	++
③ 识别能力	+	++	++	+	+	++
④ 分类、判型	−	+	++	+	+	++
⑤ 活动性判别	−	−	−	++	+	++

Key: (1). Type of sensor. (2). Positioning capabilities. (3). Recognition capabilities. (4). Classification and identification. (5). Activity distinguishing.

The functions of ESM in AEW are as follows: providing warning of possible enemy actions; goniometry and positioning for jammers; providing jammers with information about radiation sources; choosing information for antijamming; guiding jamming or tracking jamming sources; destroying jammer information (e.g., by guiding anti-radiation missiles, etc.); and jammer mobility information.

Information gained about jammer positioning and qualities from ESM can let the AEW aircraft escape. If the jammer is on the earth's surface, the AEW aircraft can change its altitude and thus lessen the effects of jamming.

Radar operation method control and radar data usage are also important antijamming methods. Intermittent radar operation, passive detection, and removing radar data in a jamming sector to prevent computer overloading are all electronic counter-countermeasures (ECCM).

(*To be continued.*)

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